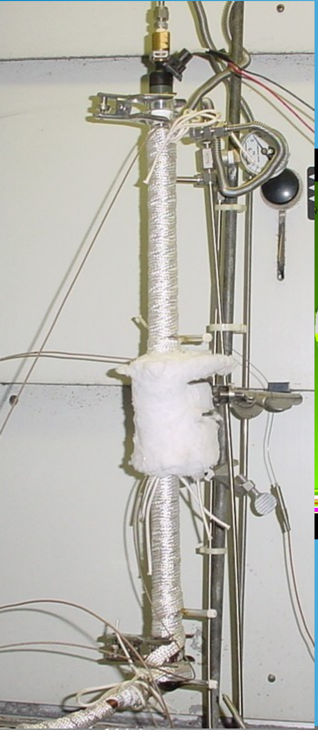
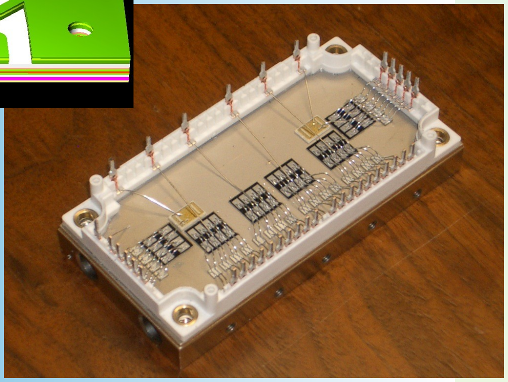
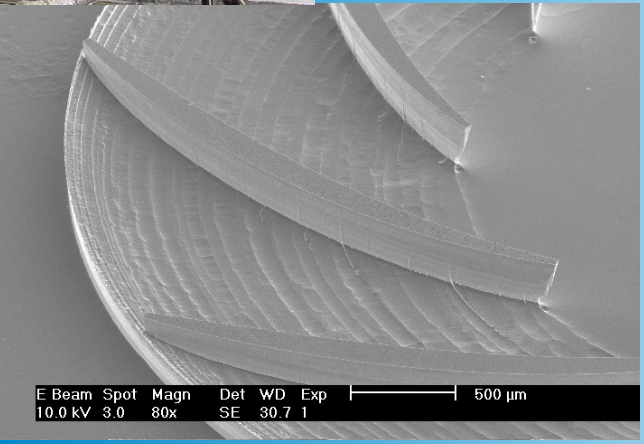
Collaborative Technology Alliance (CTA)





Power & Energy (P&E)



Mr. John Hopkins
ARL Collaborative Alliance Manager

Honeywell

Dr. Mukund Acharya
Consortium Manager, Honeywell Engines, Systems & Services

Power and Energy
Collaborative Technology Alliance

Consortium Partners

- Honeywell (lead)
- MIT
- Clark Atlanta
- Georgia Tech
- U of Maryland
- Motorola Labs
- U of New Mexico
- Case Western Reserve U
- DuPont Fuel Cells
- NuVant Systems
- U of Puerto Rico
- Penn State Univ
- Delphi Automotive
- Tufts Univ
- U of Minnesota
- U of Pennsylvania
- U of Texas – Austin
- SAIC
- United Defense LP
- Rensselear Polytechnic
- Rockwell Scientific

Objectives

Research and develop technologies that enable lightweight, compact power sources and highly power dense components that will significantly reduce the logistics burden, while increasing the survivability and lethality of the soldiers and systems of the highly mobile mounted

Technical Areas

- Portable, Compact Power Sources (Non-electrochemical)
- Fuel Cells and Fuel Reformation
- Hybrid Electric Propulsion and Power

Supporting Transformation Goals

Power and Energy
Collaborative Technology Alliance

Collaborative Alliance Manager
Mr. John Hopkins, ARL

ARL Staff
Deputy CAM Dr. Bob Bill
Asst. CAM Dr. Ivan Lee

ARL Tech. Area Leads
TA 1 Mr. Eugene Zakar
TA 2 Dr. Deryn Chu
TA 3 Dr. Ken Jones

Consortium Lead / Program Management Honeywell ES&S
Dr. Mukund Acharya

Technical Area 1
Compact Power

MIT (lead)
Prof. Alan Epstein
U. Maryland
Georgia Tech
Clark Atlanta U.

Motorola Laboratories
Honeywell Laboratories

Technical Area 2
Fuel Cells/ Reformation

Penn State U.
U. Puerto Rico
U. New Mexico
Case Western Reserve U.
U. Texas, Austin
U. Pennsylvania
Tufts U.
U. Minnesota
Georgia Tech

Motorola Labs (co-lead)
Mr. Jerry Hallmark
Delphi Automotive Systems (co-lead)
Mr. James Grieve
DuPont Fuel Cells (co-lead)
Dr. David Reichert
NuVant

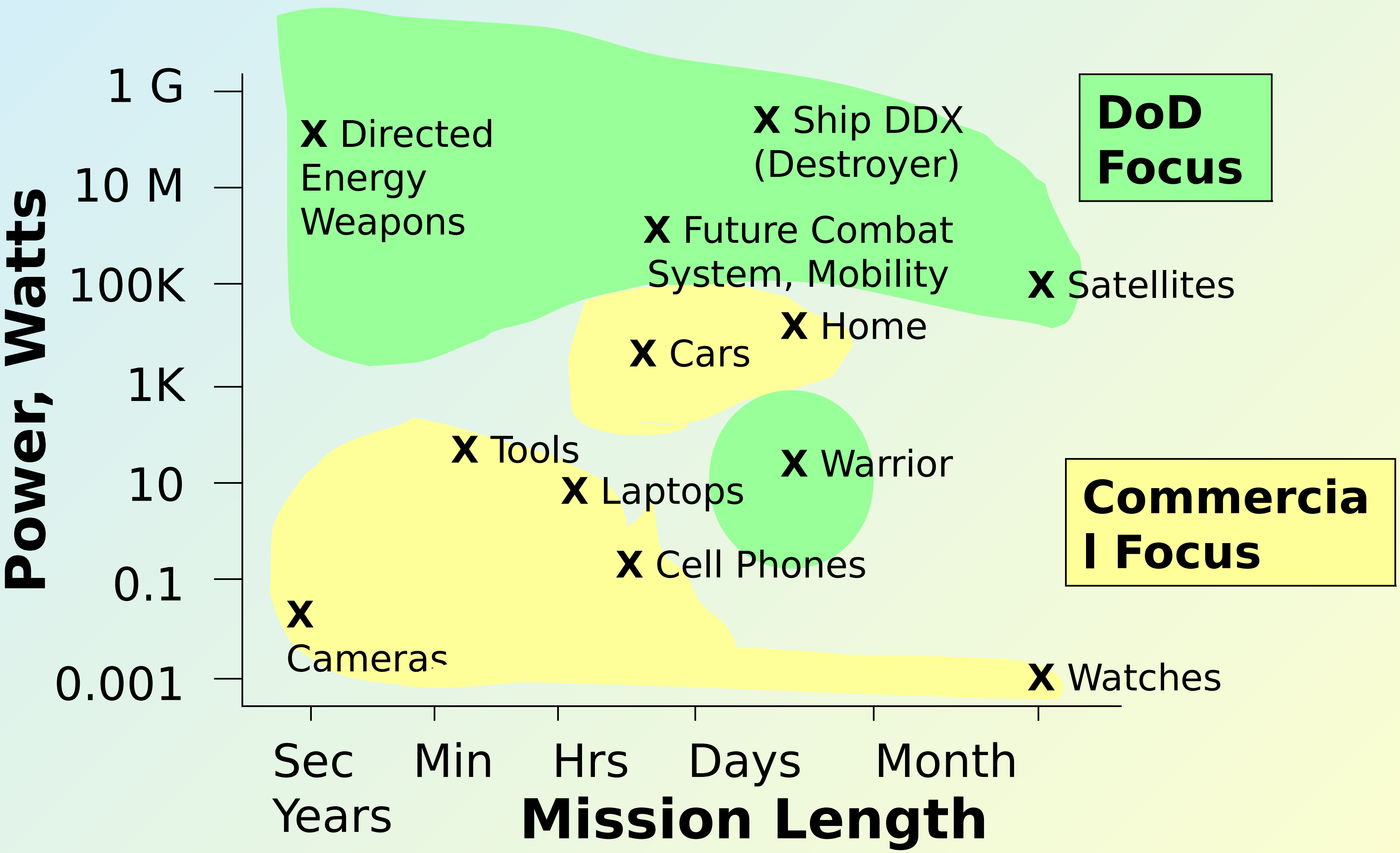
Technical Area 3
Hybrid Power and Propulsion

RPI
Texas A&M
Prairie View A&M

SAIC (co-lead)
Mr. George Frazier
Honeywell ES&S (co-lead)
Mr. Jochen Deman
United Defense
Rockwell Scientific
Cree (subcontract to SAIC)

G2486-4C

DoD and Commercial Industry Requirements



Power and Energy Taxonomy

Operational Regimes

Unit of Action

Responsive Deployable
Agile and Versatile
Lethal Survivable
Sustainable

System of Systems Platforms

Ground
Manned & Unmanned
Mobile & Non-Mobile

Air
Manned & Unmanned
Aircraft

Soldier
Future Force Warrior, Land Warrior

Unattended Ground Sensors & Munitions

Platform Applications

- Hybrid Electric/ Propulsion
- Environment Management
- Dynamic Armor
- EM, ETC, DE Weapons
- Active Protection
- C4 ISR
- Signature Management
- UGS, Munitions, Other

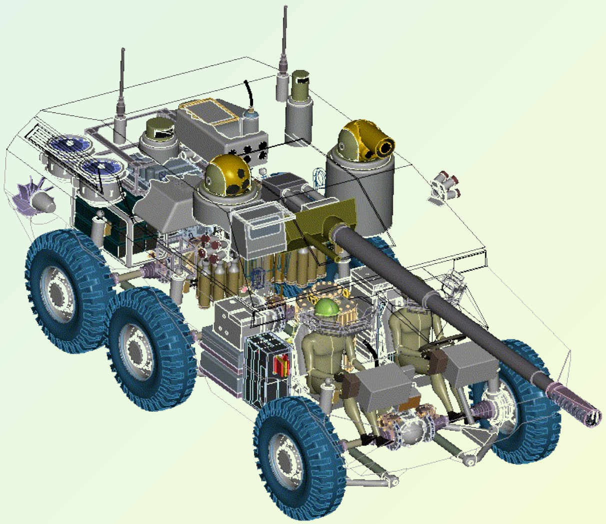
Technologies

Switches : Capacitors : Batteries : Power Converters : Fuel Cells : Fuel Reformation
Thermal Management : Power Control: Power Generation

Hybrid-Electric Combat Vehicle

Future Combat Systems

- **Common power source for propulsion, EM/ETC gun, armor, and auxiliary - ability to shift power away from propulsion**
- **Enables improved stealth, near silent watch, and extended vehicle range**
- **> 50% increase in transient power at wheels- enhances mobility**
- **Increased flexibility of vehicle system integration yields up to 10% increase in useable internal volume**



- **Required Technology**
  - **Power Generation: 2X more efficient and 2X more power dense generation**
  - **Energy Storage: Energy storage at 50 kW-hr (10’s MJ) and pulsed power capacitors up to 5 MW**
  - **Power Control and Distribution: High power switches, control and distribution**

Payoff in FY2010:

- **Fuel savings up to 50%**
- **Reduction in armor and ammunition weight hence transport costs**
- **New capability for EM/ETC gun and**

Cross-Service Critical Applications

Warrior Power

Hybrid JP-8 fueled charger/rechargeable battery system capable of:

- **eliminating non-rechargeable batteries**
- **weighing 1/3 less than non-rechargeables**
- **extending mission time per system up to 6X**

Rechargeable batteries charged 2-3X faster

Power Management design tools reduce power consumption 2 to 5 times.

Required Technology:

Energy Storage: Battery reactants with 3X increase in energy storage and 6X increase in power density. Novel liquid electrolyte reserve batteries, TRL 6, FY07.

Power Control: Efficient chargers for two hour charge time and techniques to reduce power consumption by 50% in Soldier Systems

Power Generation: Logistic fuel reformation, Direct Methanol Fuel Cells,

Return on Investment

FY08 (1 Battalion, 96 Hour Mission):

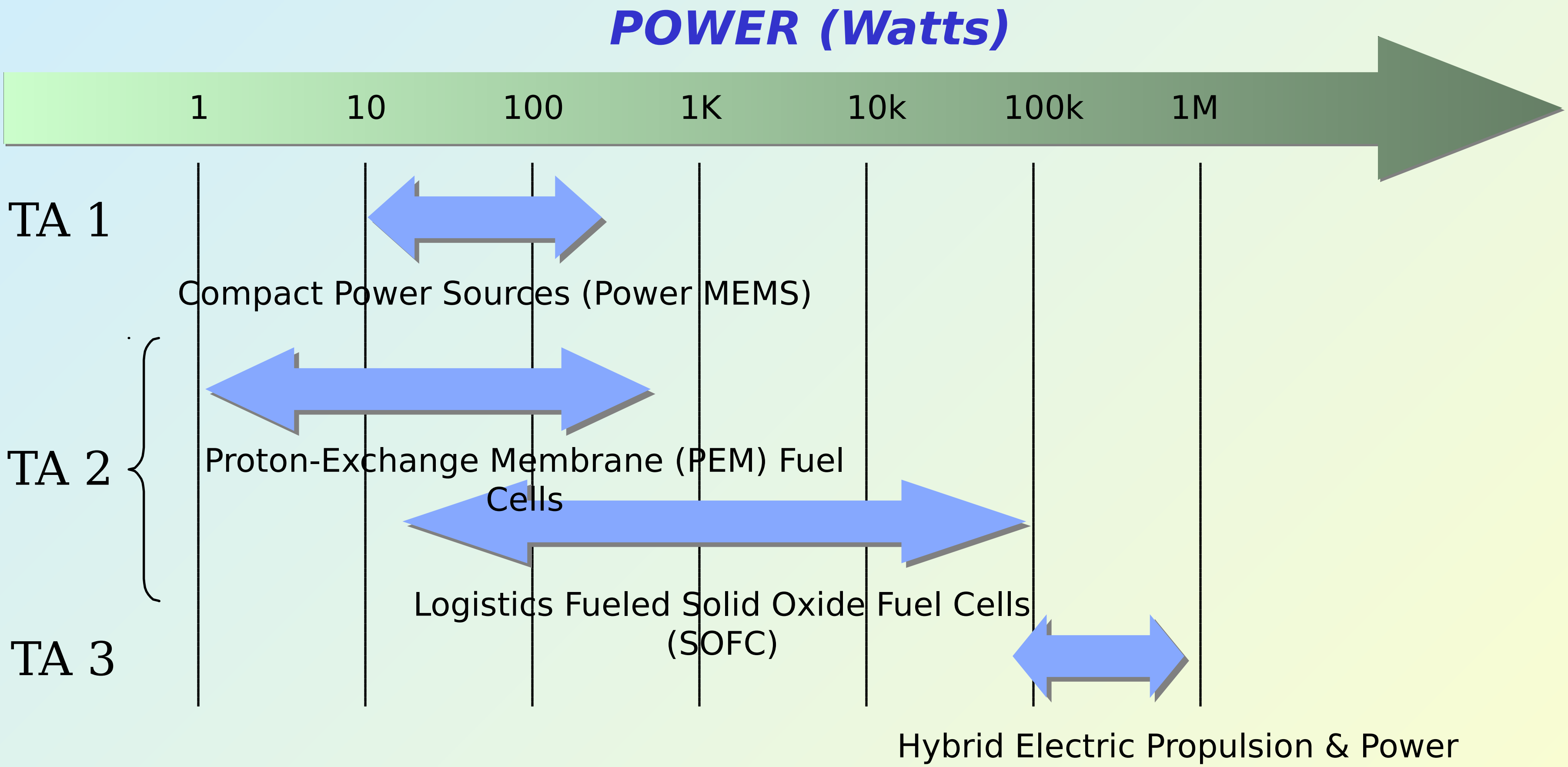
4400 Disposable Batteries, $500,000, 8800 pounds

VERSUS

200 Gallons JP-8, Rechargeable Batteries, $400, 1600 pounds for fuel

DMFC Fuel Cell Demo FY06

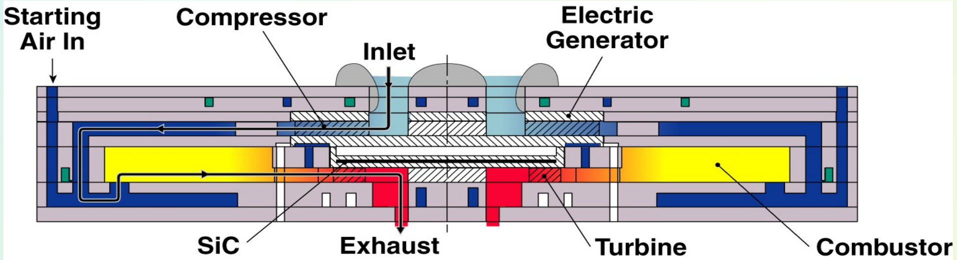
P&E CTA Focused on Three Technical Areas

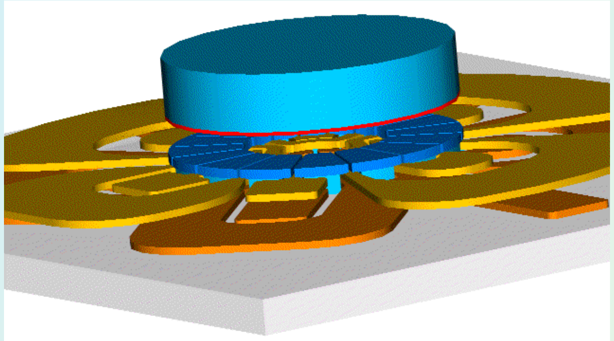


Technical Area Power Levels Meet the Goals of Transformation for Soldier and Vehicular Loads

Portable Compact Power Sources

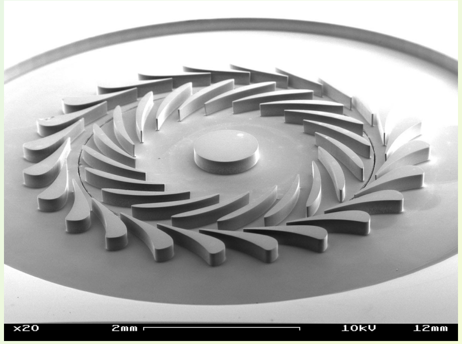
Gas Turbine & Electrostatic Generator

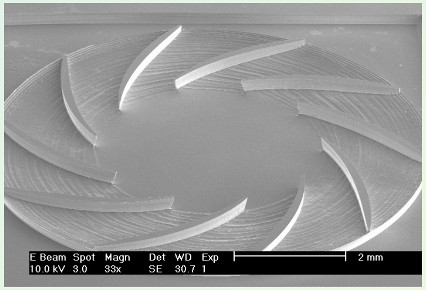




Electromagnetic Generator

Microfab Technology





Component Fabrication & MEMS Process Development

Portable Compact Power Sources

MEMS GAS TURBINE ENGINE

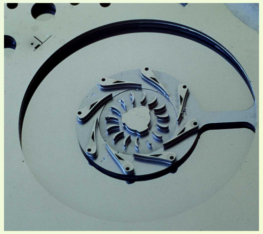
Technical Challenges:

- Improved yield from MEMS fabrication of highly complex devices
- Stable high speed rotation of silicon micro-rotors
- Silicon structure strength at high temperatures
- High performance levels from small-scale engine components

Compresso

Gas Phase Combustio
n

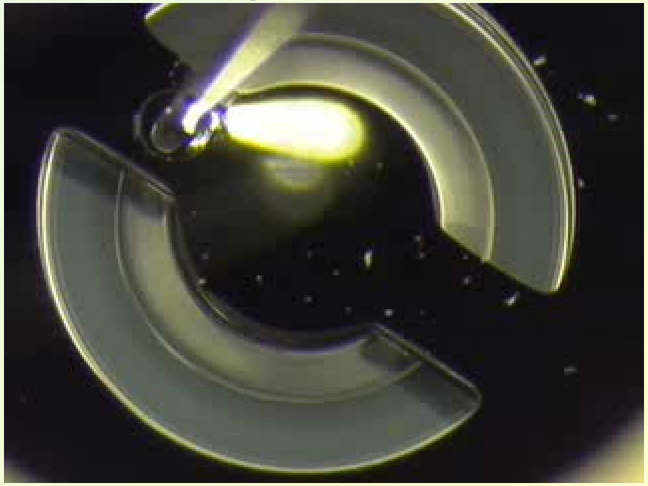
Catalytic Combustor
r



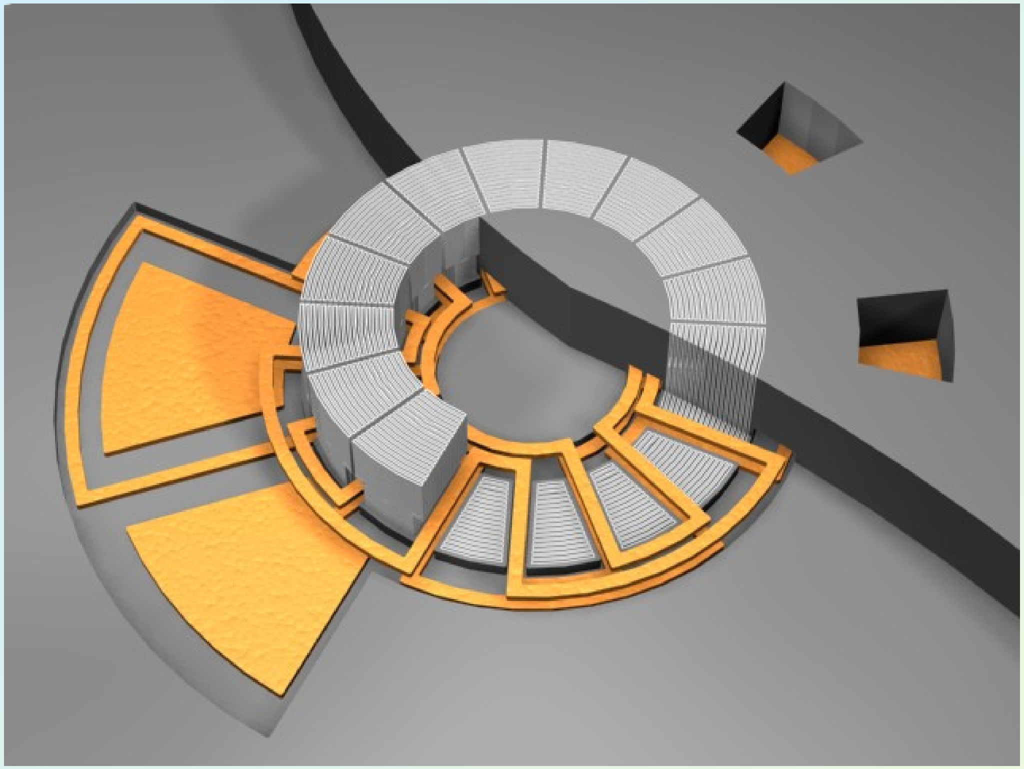
Turbine

Recent Accomplishments:

- Micro-turbocharger operated at high speed (up to 480,000 rpm)
- Micro-catalytic combustor demonstrated
- Magnetic generator device designed
- Startup model for the gas

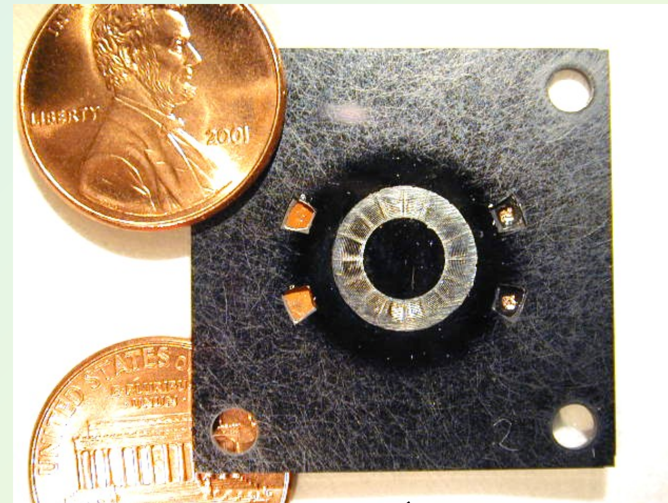


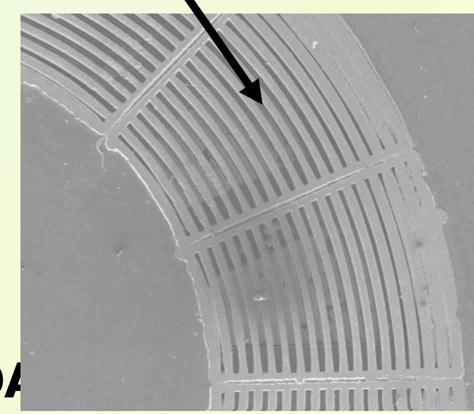
Portable Compact Power Sources
LAMINATED MAGNETIC GENERATOR STATOR



Cutaway of a MEMS magnetic generator

Fabricated induction generato



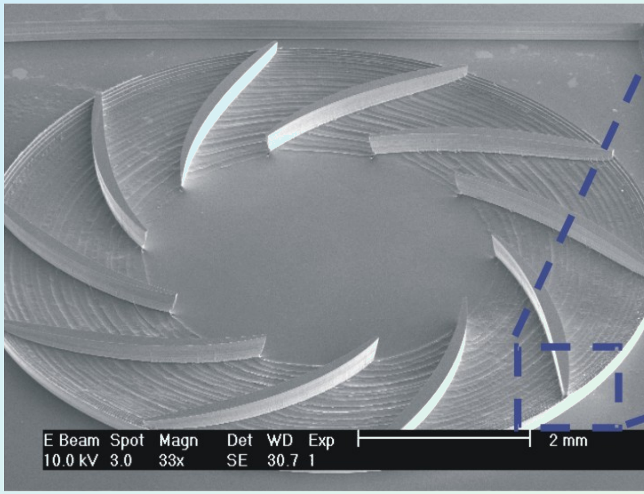


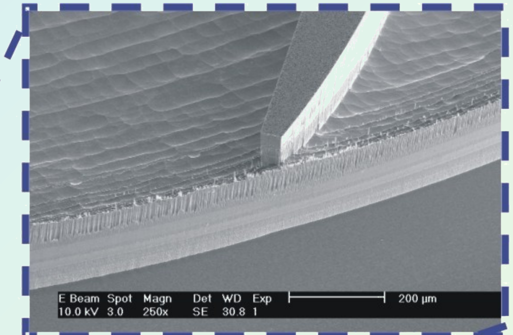
Laminated Stator

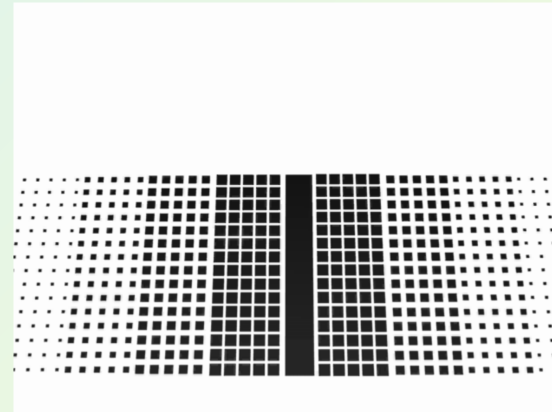
- Laminations reduce eddy current losses
- Laminated microstructures were beyond the SOA
- New fabrication processes developed & demonstrated

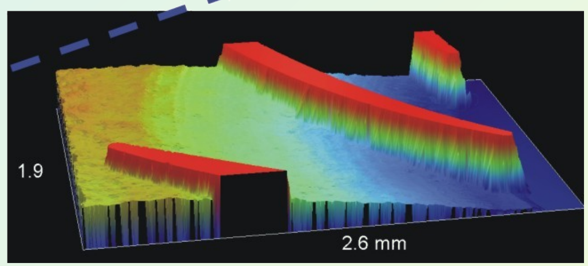
Portable Compact Power Sources

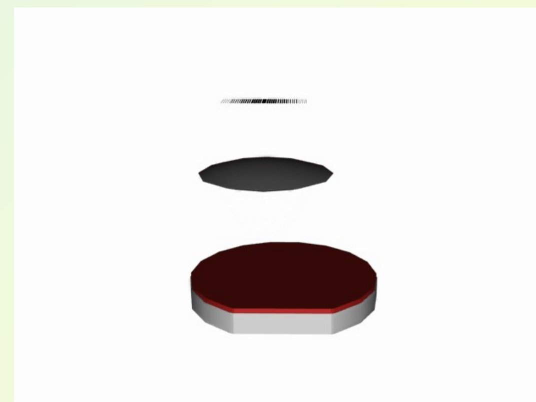
3-D Profiles in Photoresist Film







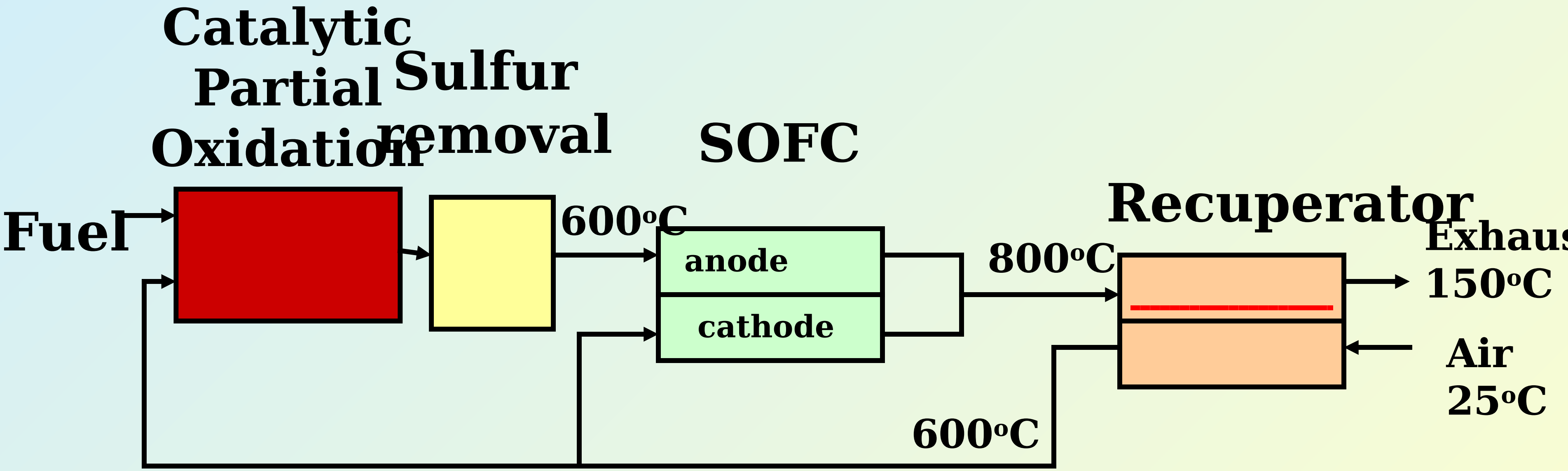




- New micromachining processes
  - Continuously variable height silicon structure demonstrated
  - Grey-scale lithography makes 3D structures possible
  - Gas turbines use extensive 3D geometries
  - Process expands gas-turbine design space, improving performance

Fuel Cells and Fuel Reformation

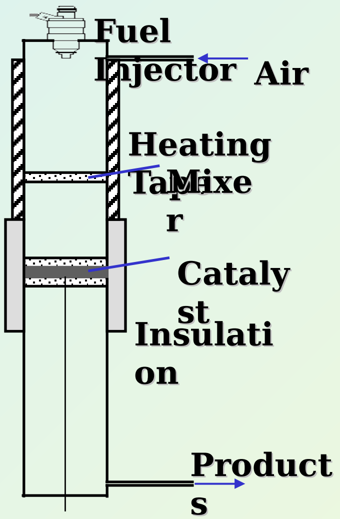
SOFC and Logistics Fuel Reformation

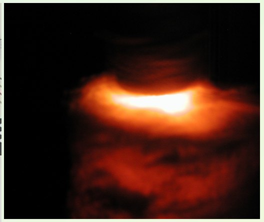


Fuel Reformation: Advanced Catalysts

Technical Challenges:

- Convert Logistic Fuels and components to Hydrogen rich gas streams for SOFCs
- Develop advanced catalysts, supports and materials for catalytic partial oxidation (CPOX)
- Obtain operating parameters and that yield high conversion
- Model reactions

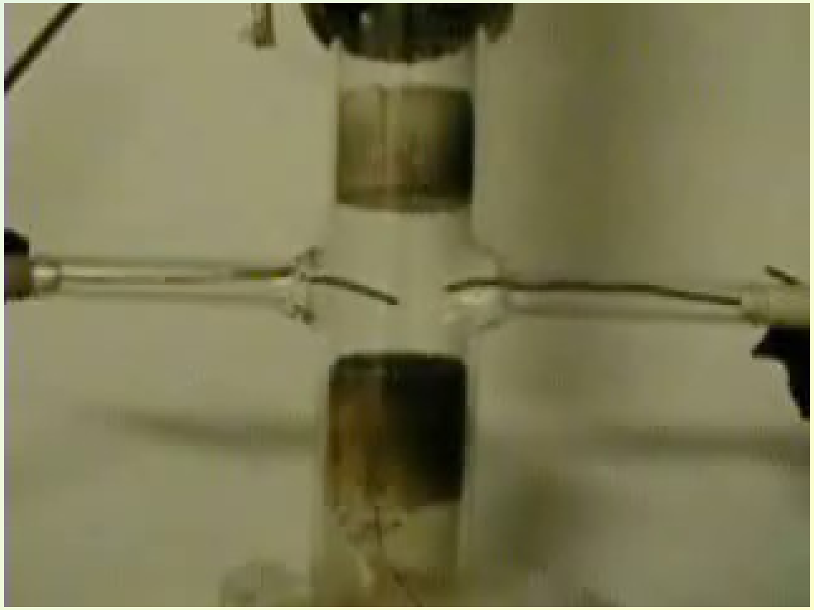




Workin
g
Catalys
t

Recent Accomplishments:

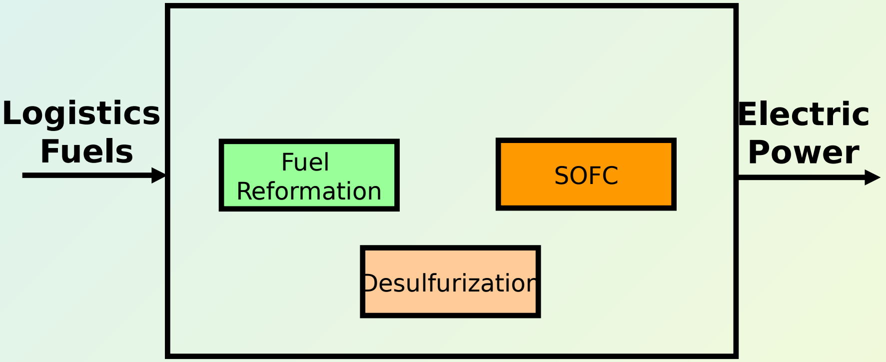
- Reformation of decane, hexadecane and low-sulphur diesel fuel
- Demonstrated fast lightoff of octane, iso octane, decane and hexadecane
- Determined limits of safe operation without flames or explosions



SOFC Stack and System Level Assessment

Technical Challenges:

- Trade-offs in power density, system efficiency and fuel tolerance drive towards higher stack temperature. Metallic interconnects are a weak link in operating above 800 C.
- Reforming, Desulfurization and Stack processes interact and must be configured into a system. Assessment of the CTA and other technical progress is needed to estimate system performance and to optimize the system for Army needs.

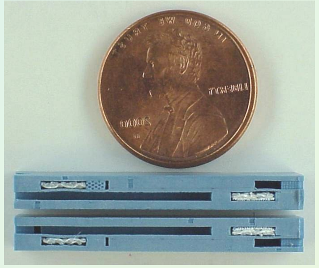


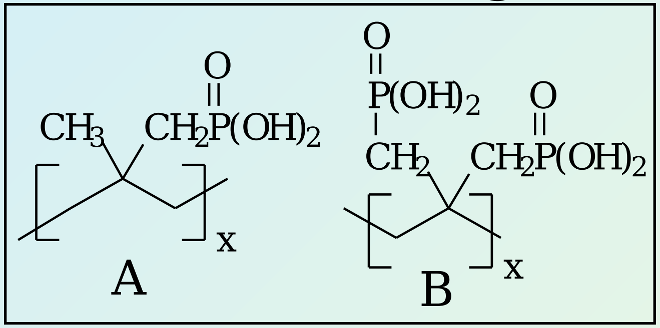
Recent Accomplishments:

- Development of screening tests for interconnect alloy evaluation.
- Development of Hysys models for system.
- Coupled proprietary version of stack electrochemical model to system model.

Fuel Cells and Fuel Reformation
Reformed Methanol Fuel Cells

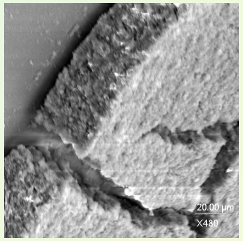
RHFC systems, peripherals, integration

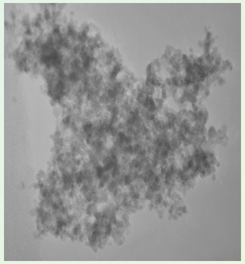




Polyphosphonic Dopants for Membranes

Reformer-ceramic materials synthesis and processing



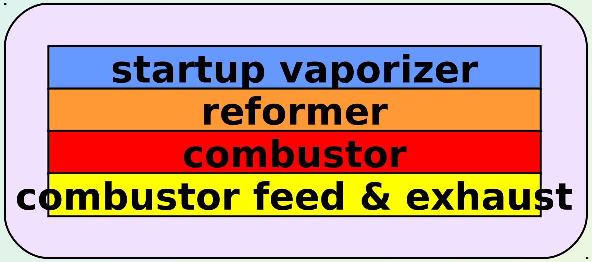


High Temperature Membranes

Reformed Hydrogen Fuel Cell System

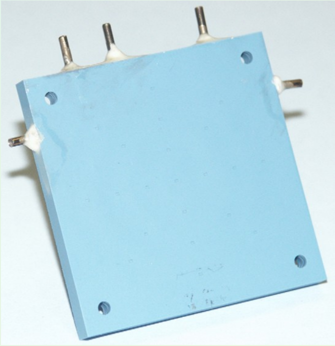
Technical Challenges:

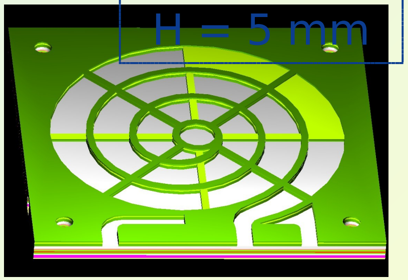
- Identify materials that are chemically compatible for long term operation of elevated temperature fuel cell stack
- Develop low-pressure-drop 20W stack with optimal characteristics
- Develop 20W fuel processor for demonstration of principle



Outer dimensions

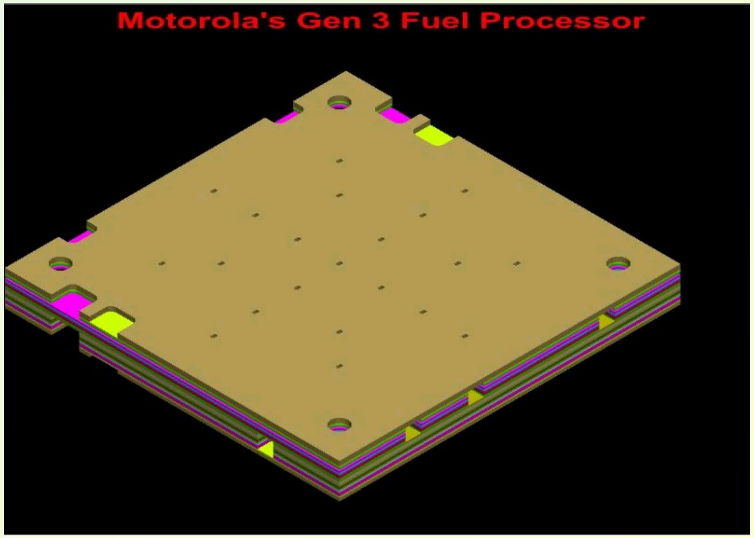
L = 49 mm
W = 49 mm
H = 5 mm





Recent Accomplishments:

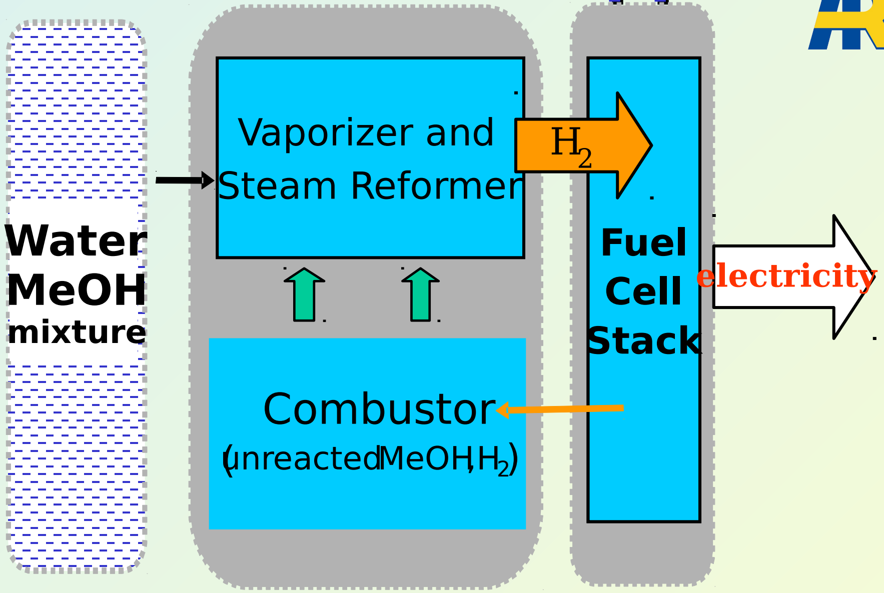
- Completed CFD model of the Gen 1 integrated fuel processor
- Completed design and construction and currently testing Gen 3.1 fuel processor (sized for 5W system)
- Demonstrated 2W proof of principle system running for >90hrs on mini-pumps with rudimentary control scheme



Reforming Catalyst in Porous Ceramic Support

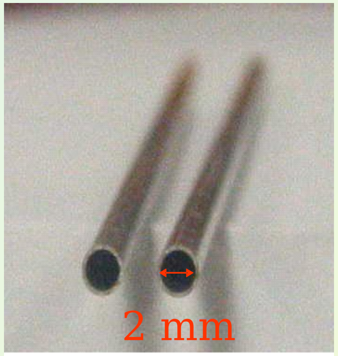
Technical Challenges:

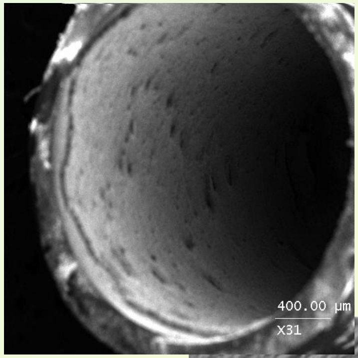
- Develop methods of wall coating of preformulated, industrial catalysts.
- Catalyst for Microchannel reformers must provide low pressure drop and high activity
- Demonstrate performance of wall coated reactor for hydrogen production
- Catalyst coating should be adherent and stable for long term use

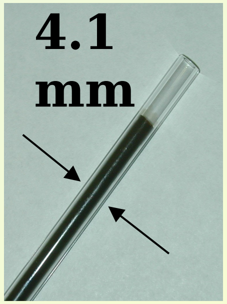


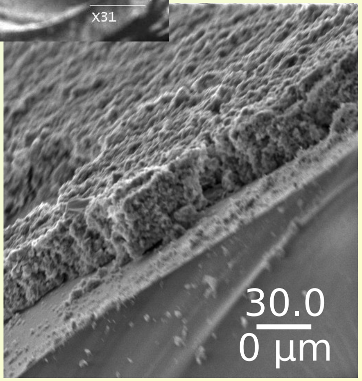
Recent Accomplishments:

- Analysis of Heat and Mass Transfer Limitations in Packed Bed and Wall Coated Reformers
- 25 µm wall coat of catalyst demonstrated within microchannels
- Reactivity of wall coated catalyst exceeds that of packed bed



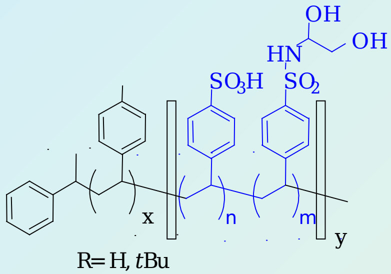






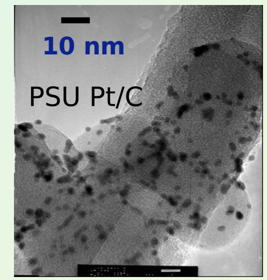
Catalyst coating, 25 µm.

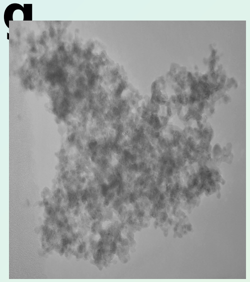
Fuel Cells and Fuel Reformation
Direct Methanol Fuel Cells



**DMFC Membranes
MEAs**

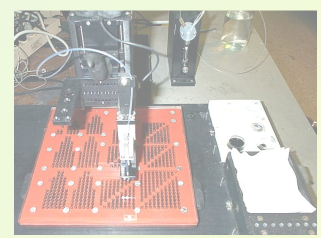
**DMFC Catalyst
Discovery
Optical catalyst
screening**

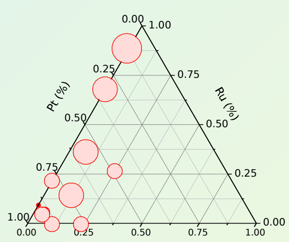




**DMFC Catalysts,
Low Methanol Crossover
Membranes**

**High throughput parallel
Screening & testing**





**DMFC anode catalyst preparation
& characterization**

DMFC System Design

Objectives

- **Design and optimize a miniature 1W DMFC system.**
- **Model scale-up to larger systems to determine overall system size, weight, and energy density.**

Challenges

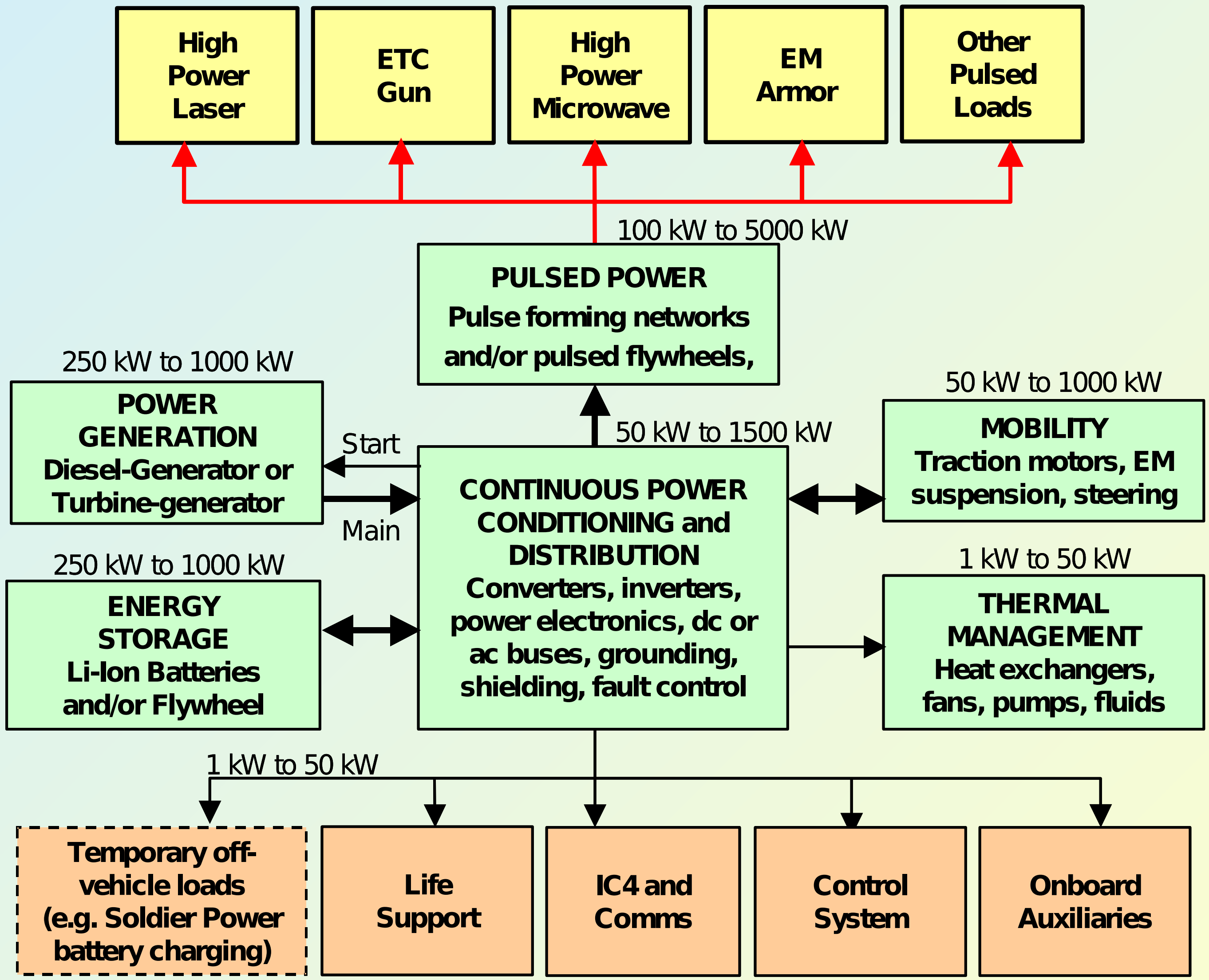
- **Integration and miniaturization of system components.**
- **Microfluidic design and processes required to maintain the structural and electrical integrity of the fuel cell system**

Accomplishments

- **1W & 2W DMFC Systems designed, built and tested.**
- **> 1000 hour operation demonstrated for 1W prototype**

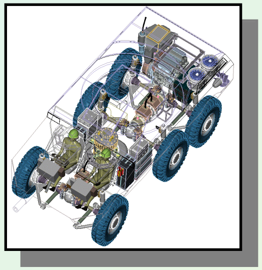
Prototype 2W DMFC System

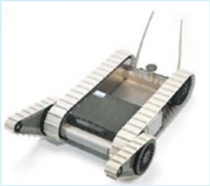
Basic Combat Hybrid Power System Architecture

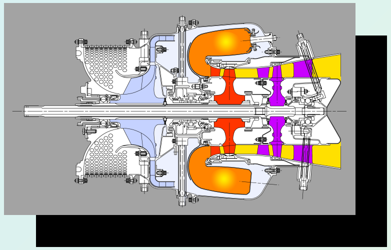


Hybrid Electric Propulsion & Power

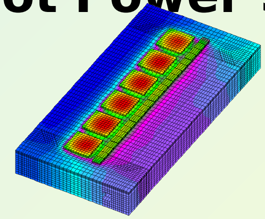
System Integration, Modeling & Analysis



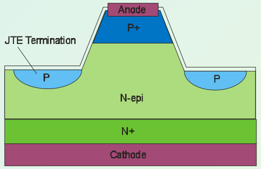




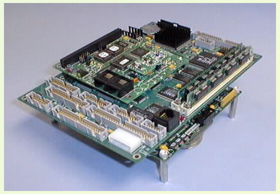
High Speed Ceramic Turbogenerator Robot Power Systems



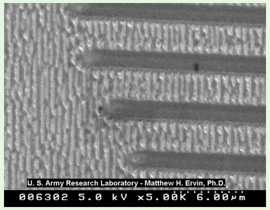
Vehicle Integration, DC-DC Converters



SiC Materials & Devices

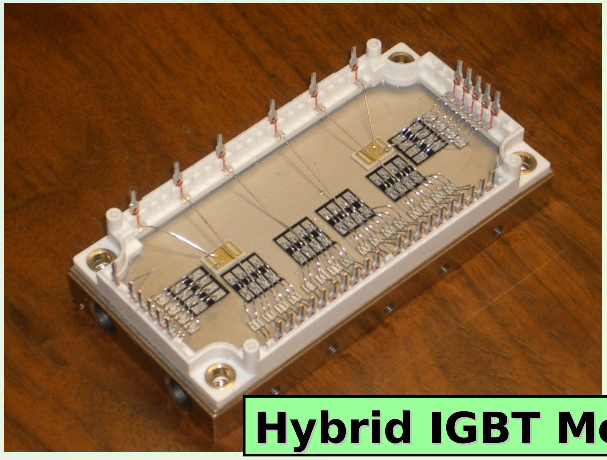


Field Sustainment Power Conditioning



SiC Device Fab, Evaluation, Process Improvements, Converter Design, Turbogenerator Technology

Hybrid Electric Propulsion & Power
Vehicle Power Conversion

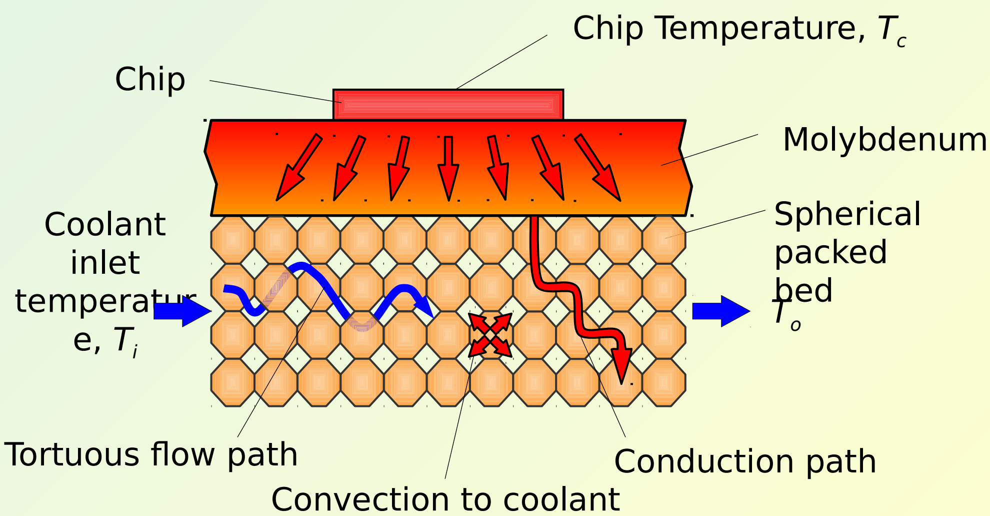

Hybrid IGBT Module

Technical Challenges:

- Development and fabrication of high temperature and high power density power electronics to meet aggressive space requirements on combat Hybrid Electric Vehicles (HEV) for FCS program.
- Develop and test hybrid Si/SiC oil cooled 600 amp/1200 volt IGBT module and integrate into an oil cooled inverter.

Recent Accomplishments:

- Designed new driver card for inverter to support thermal and electrical testing.
- Completed detail chip layout drawing for hybrid module.
- Completed bench test fixture design to electrically and thermally test module.
- Successfully developed backside and front side metallization and soldering processes for soldering SiC SBD to cold plate.
- Successfully developed and tested soldering and wire bonding processes to be used on the module.
- Completed fabrication and assembly of 4



Transitioned to CHPS SIL for Evaluation in Prototype FCS

Hybrid Electric Propulsion & Power
High-Speed Ceramic Turbogenerator

Program Objective

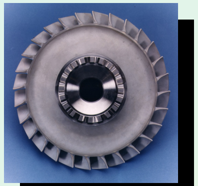
Develop and validate key technology enablers

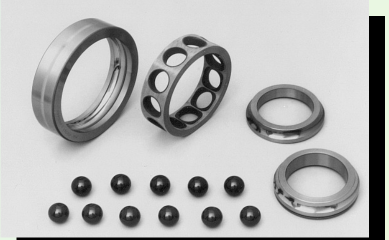
Technical Challenges:

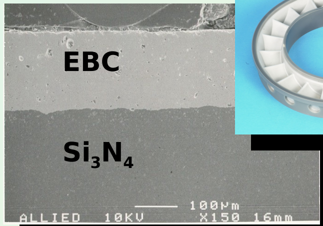
- Compact & Fuel-efficient primary energy conversion subsystem
- High cycle temperatures
- Lubrication system limitations at high speeds
- Direct-coupled high-speed generators

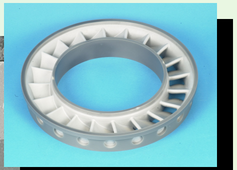
Recent Accomplishments:

- Initial screening experiments demonstrated that zirconia deposited on SiCN succesfully prevents the development of silica at this interface during oxidation.
- Initiated integration of start function in the generator for the gearless/oilless FPT engine configuration.
- Assessment of electrical machinery for the hybrid electrical drive system has been completed. Research on and development of disk (axial gap) type PM machines for both generating and

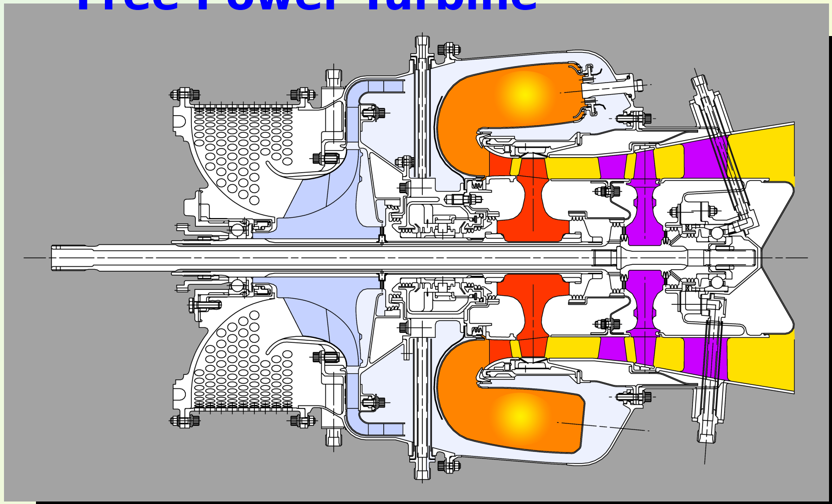






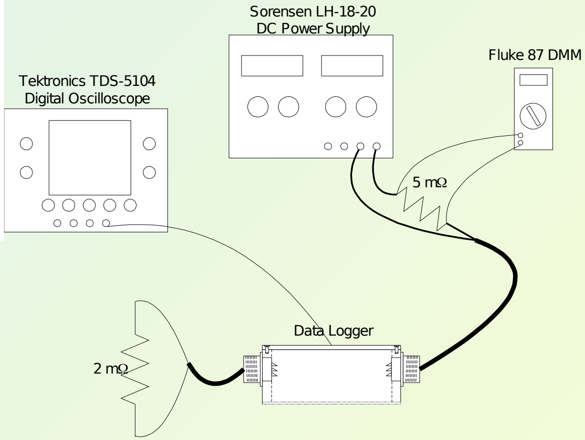


Free Power Turbine



Specific Weight = 0.2 lb/hp
Specific Volume = 0.04 ft^3/hp

Hybrid Electric Propulsion & Power
Robot Power Systems



Program Objective

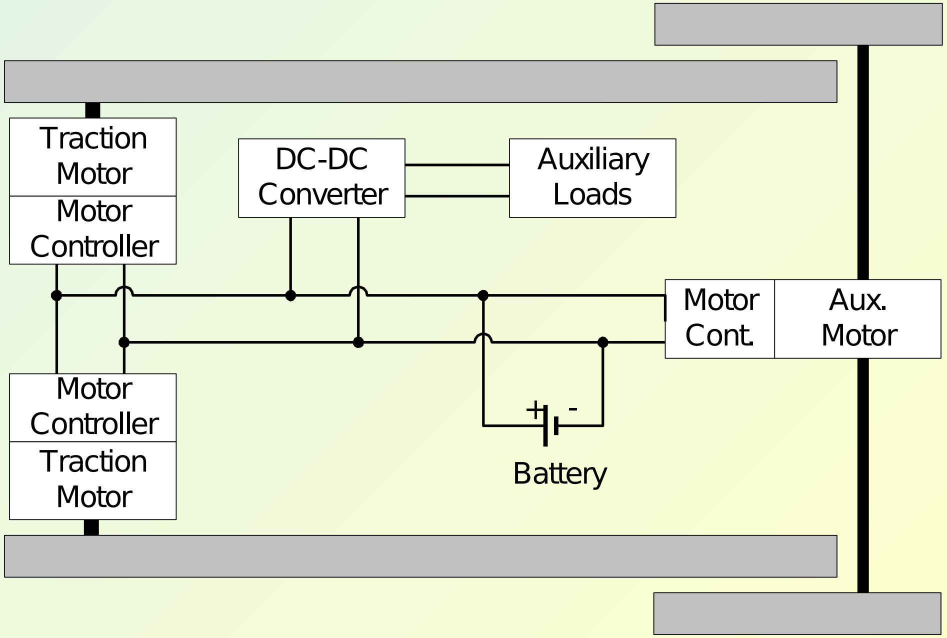
Develop and demonstrate a power system that meets the mission requirements of a man-portable autonomous robot

Technical Challenges:

- **'Small' Power System Unit up to 500W with peak and continuous power for mobility and payload**
- **Rechargeable and Expendable power pack versions**
- **Short-term solution with SOA battery technology, longer-term with fuel-cell or 'new' battery technology**

Recent Accomplishments:

- **PacBot identified as demonstration platform.**
- **Power measurements on Talon and URBOT robots completed at SPAWAR. Voltage and current demands documented for conditions simulating vehicle mission components.**



Robot Power System

Summary

- P&E CTA is part of the DoD and other agency programs to find solutions and efforts will be made to collaborate with other programs as appropriate
- P&E CTA website for Government and Consortium access
- Electric power demands continue to increase

Transformation for a Future Electric Force